



Cattle producer willingness to afforest pastureland and sequester carbon

Hannah S. Claytor^a, Christopher D. Clark^{b,*}, Dayton M. Lambert^b, Kimberly L. Jensen^b

^a Knoxville Utilities Board, Knoxville, TN, United States

^b Department of Agricultural & Resource Economics, University of Tennessee, Knoxville, TN, United States



ARTICLE INFO

Keywords:

Willingness-to-afforest

Carbon sequestration

Pasture

Triple-hurdle regression

JEL classification:

Q15

Q23

Q24

ABSTRACT

The beef industry can mitigate climate change by reducing greenhouse gas emissions associated with cattle production and increasing carbon sequestration on grazing lands. One alternative for increasing carbon sequestration is to convert pasture to forest while either reducing animal numbers or increasing cattle stocking density on more productive pastureland. This study uses data from a survey of beef cattle producers in the eastern United States to determine: (i) interest in afforesting pastureland; (ii) contingent upon interest, willingness to participate in a hypothetical afforestation program; and (iii) contingent upon willingness to participate, participation intensity in the form of enrolled acres. Less than one-third of producers were interested in afforesting pasture. Producer interest was associated with beliefs about the on- and off-farm effects of afforestation, risk aversion, age, educational attainment, opportunity costs, forest ownership, and previous experience with afforestation. Willingness to participate in the program was influenced by the incentive offered, household income, and opportunity costs. Respondents willing to participate in the program were willing to afforest an average of 55 acres, given the incentive offered. Producers with larger farms were willing to enroll more acres. Extrapolating these results to the population of beef cattle producers in the eastern United States provides a measure of the potential for pasture afforestation and carbon sequestration.

1. Introduction

Enteric fermentation and manure management attributable to livestock production account for over 42% of the greenhouse gas (GHG) emissions from agriculture in the United States (US) and about 3.5% of all US GHG emissions (USEPA, 2016). Changes in livestock production practices could lead to substantial reductions in GHG emissions (Cottle et al., 2011; Gerber et al., 2013; Hristov et al., 2013a,b; Luo et al., 2010; Montes et al., 2013). Accumulation of atmospheric GHGs could also be decreased by increasing carbon sequestration on some of the US's 614 million acres (248 million hectares) of grassland pasture and rangeland (Nickerson et al., 2011). One approach would be to afforest some of this land (Follett et al., 2001; Lee and Dodson, 1996) while either decreasing cattle numbers or increasing cattle stocking density through practices such as management intensive grazing (Gillespie et al., 2007; Jensen et al., 2015). Afforestation of pasture has been identified as a relatively cost-effective GHG mitigation strategy (Feng et al., 2006; Lubowski et al., 2006; Moulton and Richards, 1990; Parks and Hardie, 1995; Richards and Stokes, 2004; van Kooten et al., 2004).

This study informs the design and implementation of voluntary policies to increase carbon sequestration in the US by enhancing understanding of agricultural producer attitudes toward afforestation and

participation in a hypothetical voluntary program encouraging afforestation. Specifically, the willingness of cattle producers east of the 100th meridian to convert pasture to forest and how this willingness varies across livestock producers and operations is estimated using a survey of beef cattle producers. The survey was limited to livestock operations in the eastern US because of concerns over the difficulties of afforestation in the Great Plains and more arid West.

The notion of afforesting farmland to sequester carbon may be relatively recent, but programs to incentivize farmland afforestation have existed for decades (Mather, 1998). However, participation rates in these programs have often failed to match expectations (Duesberg et al., 2014a,b). Surveys of farmers suggest that producer objections to the afforestation of productive farmland may help explain lower-than-anticipated participation rates (e.g., Kassioumis et al., 2004; Frawley, 1998; Clark and Johnson, 1993; Ní Dhubháin and Gardiner, 1994; Ní Dhubháin and Wall, 1999; Gasson and Potter, 1988; Schirmer and Bull, 2011). Previous studies have investigated producer willingness to afforest agricultural land to promote carbon sequestration. van Kooten et al. (2002) and Shaikh et al. (2007) surveyed landowners in Western Canada, while Kim and Langpap (2016) surveyed landowners in western Oregon and Washington. The survey instrument used in the latter study presented respondents with a hypothetical incentive program

* Corresponding author at: 302 Morgan Hall, 2621 Morgan Circle, Knoxville, TN 37996, United States.
E-mail address: cdclark@utk.edu (C.D. Clark).

similar to the one used in this study.¹ Forty-eight percent of the Kim and Langpap (2016) respondents were unwilling to afforest agricultural land even if the “right” conditions and incentives were offered. Thus, one hypothesis of this study is that a sizable share of respondents will be uninterested in afforesting pasture and unwilling to enroll in an afforestation program. However, a survey of Australian landowners found that 80% were at least interested in afforesting to affect carbon sequestration (Schirmer and Bull, 2011), suggesting that producer attitudes toward afforestation might vary by region and over time.

2. Survey data

Data were collected with a mail survey of beef cattle operations with at least 20 head of cattle in the eight US Department of Agriculture-Economic Research Service (USDA-ERS) production regions east of the 100th meridian (i.e., Heartland, Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, and Mississippi Portal) (USDA-ERS, 2000).² A stratified random sample of 8875 operations was drawn by the USDA's National Agricultural Statistics Service (NASS) from the population of 267,413 farms. Survey strata were based on ERS production regions and farm sales classes (i.e., < \$10,000; \$10,000–\$29,999; \$30,000–\$49,999; \$50,000–\$99,999; \$100,000–\$149,999; \$150,000–\$199,999; \$200,000–\$499,999; > \$500,000). Sampling intensity was based on a 3% margin of error with a 95% confidence interval. Post-stratification weights were generated based on a cross tabulation of farm sales classes and ERS regions (Lambert et al., 2014). USDA/NASS fielded the survey in 2013 with an initial mailing, a reminder postcard (one week after the first mailing), and a second follow-up mailing (two weeks after the reminder). A total of 2448 completed surveys were returned for a 28% response rate. After eliminating observations with missing entries, there were 1026 surveys were available for this analysis. Expanding the sample by the survey weights results in a projected 112,445 farms.

The survey instrument consisted of three sections. The first section included questions on farm characteristics. Section two provided respondents information on afforestation and how it could benefit their operation and the environment (Fig. 1), along with regionalized estimates of establishment and maintenance costs (Fig. 2). Three questions on respondent willingness to afforest and participate in a hypothetical afforestation incentive program followed (Fig. 3). The first question asked about respondent willingness to afforest pastureland and provided respondents with three response options: not willing even if afforestation was profitable, willing to afforest only if it was profitable, and willing to afforest even if it was unprofitable. Respondents unwilling to afforest even if profitable (“Non-adopters”) were asked to skip the other questions in the choice experiment. Respondents who indicated they were either willing to afforest if profitable or willing to afforest even if not profitable (“Adopters”) were asked if they would, hypothetically, participate in a program that would pay them 75% of the costs of afforesting pastureland in addition to an annual payment for ten years for each acre of pastureland afforested (Fig. 1). While this question did not explicitly reference any program conditions beyond the ten-year payment period, the survey's description of afforestation and voluntary afforestation incentive programs states that “these programs allow trees to be sustainably harvested at the end of the program period,” but “may prohibit the forest product that is harvested from being burned or turned into fuel” (Fig. 1). The amount of the annual per

acre payment – which was informed by a pretest of the survey instrument with 300 producers – varied randomly across surveys between \$60, \$90, \$120, \$150, and \$180 per acre (\$148.26, \$222.39, \$296.53, \$370.66, and \$444.79 per hectare). Respondents willing to participate in the hypothetical program, given the incentive offered, were then asked how many acres they would afforest. The last set of questions in this section of the survey asked respondents about the factors influencing their responses to the choice experiment questions and their perceptions of the on-farm impacts associated with pastureland afforestation. The final section of the questionnaire included attitudinal questions and questions pertaining to respondent characteristics.

One way to assess the representativeness of the sample used in this analysis is to compare average values of farm or farmer characteristics to average values from the 2012 Agricultural Census for those states either wholly or partly east of the 100th Meridian. However, the value of this comparison is somewhat limited by the fact that our sample is of beef cattle operations with at least 20 head of cattle as opposed to all farms in this region. Given this qualification, the average farm size for our sample (267 acres) is smaller than that reported in the Census (357), while our respondents are, on average older (62 to 58 years) and less likely to work off-farm (52 to 61%) than all principal operators in the region. Possible explanations for these differences include the difference in populations (beef cattle producers as opposed to all farmers) and non-response bias.

3. Economic model

The skip pattern of the survey is accommodated by a tiered modeling approach (Jensen et al., 2015; Qualls et al., 2012) that extends Heckman's (1976) sample selection model. The triple hurdle regression model encompasses three levels of analysis: (1) willingness to afforest pastureland; (2) willingness to commit to the hypothetical incentive program, given willingness to afforest and the per acre incentive offered; and (3) participation intensity, gauged by the number of acres the respondent would be willing to enroll into the hypothetical program, given willingness to commit to the program and accept the incentive. The three-tiered hurdle model allows the factors influencing responses to vary across the three decision tiers.

In the absence of an incentive, afforestation is hypothesized to occur when the producer's utility (u) from afforesting pasture (A) is at least as great as the producer's utility without afforesting. In other words, producer i afforests when $u_1(1, I_i; X_i) + e_{i1} \geq u_1(0, I_i; X_i) + e_{i0}$, where 1 denotes afforestation of pastureland, 0 otherwise; I is income; X is a vector of operator characteristics and farm attributes affecting the decision to afforest; and e is a stochastic unobserved component of utility. Utility is a random variable, and the likelihood of a producer expressing interest in a program can be extended to a probabilistic framework (Shaikh et al., 2007). For example,

$$\begin{aligned} Pr(AFFOREST_i = 1 | X_i) &= Pr(u_1(1, I_i; X_i) \\ &\quad + e_{i1} > u_1(0, I_i; X_i) + e_{i0}) \\ &= Pr(X_i \theta_1 + e_{i1} > X_i \theta_0 + e_{i0}) \\ &= Pr(X_i (\theta_1 - \theta_0) + e_{i1} - e_{i0} > 0) \\ &= Pr(\varepsilon_{i1} > -X_i \beta_1) \end{aligned} \quad (1)$$

Assuming the stochastic component is normally distributed with an expected value of zero and variance of one,

$$Pr(AFFOREST = 1) = \Phi(X_i \beta_1) \quad (2)$$

where Φ is the standard normal cumulative distribution function.

Along these lines, the first tier of the model distinguishes respondents interested in and potentially willing to afforest ($AFFOREST$) from those unwilling to afforest even if the practice is profitable as a latent variable:

¹ The primary differences in the hypothetical programs are that Kim and Langpap (2016) offered respondents a 50% cost share and annual payments for 15 or 30 years for afforesting either cropland or grassland, while the hypothetical program in this study offered respondents a 75% cost share and annual payments for 10 years for afforesting pasture.

² The 100th meridian roughly divides the continental US in half – running from Texas through the Dakotas – and is a commonly used line of demarcation between the eastern and more arid western US.

Afforestation

The next section asks you some questions about afforestation. Before answering these questions, we ask that you read the following to ensure that you understand how afforestation is defined in this survey.

What is afforestation?

- Afforestation is the *conversion of bare or cultivated land into forest*. For example, afforestation can occur by converting marginal pasture or cropland to fast growing trees or to native species.
- There are a variety of programs that pay landowners to convert pasture or cropland to forest in order to remove carbon, a greenhouse gas, from the atmosphere. These programs typically prohibit landowners from harvesting the trees, including thinning, for a certain period of time.
- While these programs allow trees to be sustainably harvested at the end of the program period, they may prohibit the forest product that is harvested from being burned or turned into fuel in order to prevent the release of the carbon stored in the trees back into the environment.

How would afforestation benefit you?

- Enhances potential wildlife habitat which could provide hunting and wildlife viewing opportunities
- Provides a buffer from surrounding landscapes
- Can produce fast-growing trees on marginal lands

What would you need to do to afforest your land?

Before afforestation:

- Prepare the site (removal of competing vegetation, seedbed preparation -mowing, tillage and herbicide application)
- Plant the trees (plants, labor for plant, shelters and mats, shipping and handling, hand planting vs. mechanical planting)

Afforestation maintenance:

- Maintain the stand (weeding, mowing, herbicide application, tilling, herbivore control)
- Replant trees (account for minimum survival rate in trees per area)
- Have afforestation monitored periodically
- Keep records of forest maintenance
- At the end of the program, either maintain the stand or limit harvest to sustainable methods



Fig. 1. Afforestation information screen.

Q11. The following table provides cost estimates (by region) for the establishment and maintenance of afforested land. Please review the cost estimates for your region before answering the questions below. We realize that these costs will vary depending on where you purchase the materials.

Region ^{aa}	Establishment Costs/Acre (Year 1) ^a	Maintenance Costs/Acre (Year 2)	Maintenance Costs/Acre (Avg. in Years 3-10)
Appalachia	\$300	\$84	\$49
Corn Belt	\$304	\$87	\$49
Delta	\$300	\$84	\$49
Lake	\$303	\$87	\$49
Northeast	\$300	\$84	\$49
Northern Plains	\$303	\$86	\$49
Southeast	\$260	\$116	\$49
Southern Plains	\$302	\$82	\$49

^aNortheast: CT, DE, ME, MD, MA, NH, NJ, NY, PA; Lake States: MN, WI, MI; Corn Belt: IL, IN, IA, MO, OH; Northern Plains: KS, NE, ND, SD; Appalachia: KY, NC, TN, VA, WV; Southeast: AL, FL, GA, SC; Delta: AR, LA, MS; Southern Plains: OK, TX.

^bThe example fast growing woody crop is hybrid poplar for all regions but the Southeast which is pine. Based on US Billion Ton Update (Oak Ridge Natl Lab.).

^c Forest establishment costs include cuttings, plantings, machinery, fertilizer, and chemicals; Maintenance costs in year 2 include cultivation, fertilizer, and herbicide; Maintenance costs in years 3 to 10 include cultivation and fertilizer.

Fig. 2. Afforestation cost estimates by region.

$$AFFOREST_i^* = X_i\beta_1 + \varepsilon_{1i} \quad (3)$$

$$AFFOREST_i = \begin{cases} 1, & AFFOREST_i^* > 0 \\ 0, & AFFOREST_i^* \leq 0 \end{cases} \quad (4)$$

where X are still farm attributes and farmer characteristics, including attitudinal variables related to factors influencing willingness to afforest, perceptions of the effects of technology acceptance, and self-perceived roles of stewardship and civic responsibility. Since

afforestation could affect utility directly, in terms of the utility or disutility the producer would receive from afforesting pasture lands, and indirectly, through the effect of afforestation on producer profits, this first tier also includes a variable representing the producer's expectations as to the effects of afforestation on farm profits.

Eq. (4) eliminates respondents who would be unlikely to expend the effort needed to learn about and consider participation in an afforestation program from being confronted with a hypothetical choice

Which of the following best describes whether you would adopt or expand afforestation? Check one answer.

I would not adopt or expand afforestation if it was profitable to do so. ☐ → Skip to Q22 on page 5

I would adopt or expand afforestation even if it was not profitable to do so. ☐ → Continue to Q12

I would adopt or expand afforestation only if it was profitable to do so. ☐ → Continue to Q12

Q12. We are now going to ask you about a HYPOTHETICAL PROGRAM to encourage farmers and ranchers to adopt or expand afforestation of pastureland. Assume the program would:

- Pay 75% of the costs of purchasing and installing the components needed to begin afforestation on pastureland acres on your farm or ranch;
- Pay you continuing annual payments for 10 years if you follow all of the practices described in the box on page 4 and document these practices each season;
- Not limit the number of acres you can enroll; and
- Be limited to acres not enrolled in another conservation program.

Would you be willing to convert acreage on your farm to forestland for a 10 year period if you were offered a) the 75% installation cost share described above and b) an ANNUAL payment of \$180 per acre for each of the 10 years you practice afforestation?

Yes, I would adopt or expand afforestation ☐ → Continue to Q13 No, I would not adopt or expand afforestation ☐ → Skip to Q22 on page 5

Q13. If yes, how many acres would you afforest? Acres

Fig. 3. Choice experiment.

experiment about one, potentially reducing the opportunities for hypothetical bias. Willingness-to-pay (WTP) studies often use this type of screening question to distinguish individuals for whom WTP is equal to zero (i.e., those for whom the price cannot go low enough to induce them to buy – i.e., a “corner solution”) from those whose reservation price has not yet been met (Jensen et al., 2015). The concept of zero WTP may not have a clear corollary in a willingness-to-adopt context because a large enough subsidy would likely induce near-universal, if not universal, participation. However, inducing hypothetical participation among individuals unwilling to expend the resources necessary to learn about a real program has the potential to introduce its own form of bias. In any event, accounting for self-selection out of the willingness-to-adopt exercise is important to minimize bias arising from corner solution cases. This bias is reduced by estimating the first tier of the model jointly with the second and third tiers discussed below (Jensen et al., 2015).

Producers interested in afforestation (i.e., $AFFOREST_i = 1$) are assumed to be willing to participate in an afforestation program when the utility from participating ($COMMIT_i = 1$) is at least as great as the utility from not participating. Assuming again the utility from this decision can be modeled as a linear index function, the probability of voluntarily committing to the hypothetical program is:

$$\begin{aligned}
 Pr(COMMIT_i = 1, AFFOREST_i = 1 | X_i) &= Pr(u_2(1, \pi_i + c_i; X_i) + (v_{11} | \varepsilon_{1i}) - X_i \beta_1) > u_2(0, \pi_i; X_i) \\
 &\quad + v_{10} | (\varepsilon_{1i}) - X_i \beta_1) \\
 &= Pr(X_i(\gamma_1 - \gamma_0) + (v_{11} - v_{10}) | (\varepsilon_{1i} > -X_i \beta_1) > 0) \\
 &= Pr(\varepsilon_{2i} > -X_i \beta_2, \varepsilon_{1i} > -X_i \beta_1) \\
 &= \Phi_2(X_i \beta_2, X_i \beta_1, \rho_{12})
 \end{aligned} \tag{5}$$

where Φ_2 is the standard normal bivariate cumulative distribution function; ρ_{12} measures the correlation between ε_{1i} and ε_{2i} ; π is producer profits; c is the difference between the incentive payment for participating in the program and the producer's costs of participation, including the opportunity costs of afforestation; X is as before; and v are unobservable stochastic components of utility. Utility is also a random variable in this stage, conditional on the perceived utility from afforestation. The first and second hurdles are a bivariate probit with sample selection (Van de Ven and Van Praag, 1981). The empirical model is:

$$COMMIT_i^* = \alpha_2 \cdot INCENTIVE_i + X_i \beta_2 + \varepsilon_{2i} \varepsilon_{1i} > -X_i \beta_1 \tag{6}$$

$$COMMIT_i = \begin{cases} 1, & COMMIT_i^* > 0 | AFFOREST_i^* > 0 \\ 0, & COMMIT_i^* \leq 0 | AFFOREST_i^* > 0 \end{cases} \tag{7}$$

where $INCENTIVE$ is the cost share payment encouraging the conversion of pastureland to forest. This second tier of the model determines whether the incentive offered triggers the allocation of land, time, and other resources to participate in the voluntary program and afforest.

Producers willing to accept the incentive and participate in the program were also asked to indicate the intensity of their willingness by stating how many acres they would enroll into the program (i.e., afforest):

$$ACRES_i^* = \alpha_3 \cdot INCENTIVE_i + X_i \beta_3 + \varepsilon_{3i} | \varepsilon_{1i} > -X_i \beta_1, | \varepsilon_{2i} > -X_i \beta_2 \tag{8}$$

$$ACRES_i = \begin{cases} ACRES_i^*, & COMMIT_i^* > 0 | AFFOREST_i^* > 0 \\ - , & COMMIT_i^* \leq 0 | AFFOREST_i^* > 0 \\ - , & - | AFFOREST_i^* < 0 \end{cases} \tag{9}$$

where $ACRES_i^*$ (i.e., participation intensity) is a latent variable observed only if the landowner expresses interest in afforesting and willingness to participate in the program, given the incentive offered, and ε_{3i} is an iid error term. The observed acres enrolled is log-transformed to reduce the effect of outliers and to ensure that predictions of acreage enrollment are strictly positive. Operation size is likely to be an important determinant of acreage enrollment. Presumably, scale effects influencing the acreage supply function are fixed in the short term; i.e. that the size of the operation managed directly influences the operator's determination of how much pasture acres to afforest.

The equation system is summarized as a path diagram in Fig. 4. It is important to note that the errors may be correlated across decision tiers, as Fig. 4 suggests. For example,

$$\begin{bmatrix} \varepsilon_{1i} \\ \varepsilon_{2i} \\ \varepsilon_{3i} \end{bmatrix} \sim MVN \left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{12} & 1 & \rho_{23} \\ \rho_{13} & \rho_{23} & \sigma^2 \end{bmatrix} \right), \tag{10}$$

where the ρ_{jk} are correlation coefficients, MVN is the multivariate normal distribution, and σ is the standard deviation of the error terms associated with the acreage allocation decision. This correlation structure links the sequential decisions made by the producer in the adoption decision.

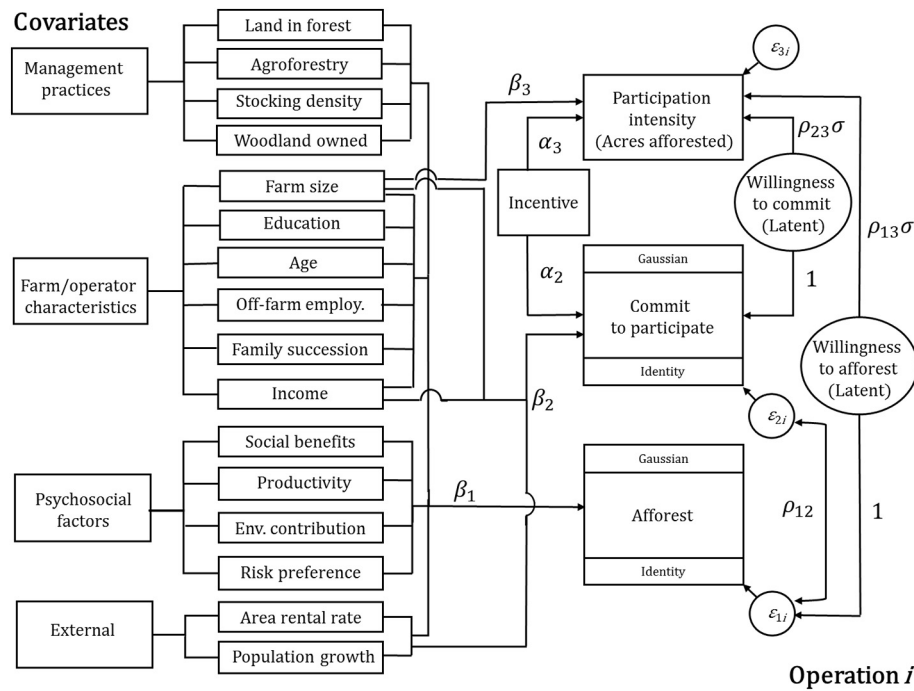


Fig. 4. Path diagram of triple hurdle model.

Table 1
Factor analysis.

Variable	Factor 1	Factor 2	Factor description	
Importance of factor on decision to afforest:				
Amount of time required	0.7807	0.2550	“Economic Factors” (ECONOMIC)	
Investment cost	0.8511	0.3051		
Amount of paperwork	0.7367	0.3176		
Per acre payment offered	0.6410	0.5281		
Limitations on end uses of timber	0.5696	0.4630		
Offset carbon emissions	0.2814	0.7161	“Social Benefits” (SOCBENES)	
Own level of knowledge about afforestation	0.4786	0.6207		
Impact of afforestation on the environment	0.3913	0.7386		
Availability of Extension services	0.5038	0.4869	“Production Benefits” (PRODUCTION)	
Attitudes of friends	0.2086	0.2897		
Likelihood of afforestation causing factor:				
Reduce soil erosion on farm	0.8036	0.3376		
Improve water quality on farm	0.8212	0.2999		
Improve farm appearance	0.6094	0.4865		
Improve wildlife habitat	0.5867	0.2644		
Free up land for other ag. Uses	0.3412	0.7560		
Improve forage	0.3465	0.7869		
Increase feed costs	0.2452	0.4444		
Observations	1026			

Bold values represent standardized factor loadings exceeding 50%.

Roodman's (2011) Conditional Mixed Process program (*cmp*) was used to estimate the system, using probit models for the first (*AFFOREST*) and second (*COMMIT*) tiers and a continuous model for the third tier (*ACRES*). The weighted likelihood function was maximized using the Newton-Raphson procedure (Gould et al., 2010).

Jensen et al. (2015) extend Yen and Rosinski's (2008) and Cameron and Trivedi's (2009) conditional expectation to estimate the conditional expected value of acres enrolled into the program (*ACRES*) as:

$$\begin{aligned}
 E(ACRES_i | ACRES_i > 0, AFFOREST_i = 1, INTEREST_i = 1) \\
 = \exp\left(\alpha_3 \cdot INCENTIVE_i + X_i \beta_3 + \frac{\sigma^2}{2}\right) \\
 \cdot \frac{\Phi_2(\alpha_2 \cdot INCENTIVE_i + X_i \beta_2 + \sigma \rho_{13} X_i \beta_1 + \sigma \rho_{23} \rho_{12})}{\Phi_2(\alpha_2 \cdot INCENTIVE_i + X_i \beta_2 + X_i \beta_1 \rho_{12})}
 \end{aligned}
 \quad (11)$$

The marginal effects of the first and second hurdles and Eq. (11) are estimated using a finite difference approximation (Cameron and Trivedi, 2009).

3.1. Factor analysis

Principal factor analysis was used to analyze responses to questions regarding the importance of factors influencing the respondent's decision to participate in the afforestation program and the likelihood that participation would affect the respondent's operation in various ways. Principal factor analysis partitions variables into groups based on correlations among group members. However, the factors resulting from the analysis are orthogonal allowing a set of related variables to be collapsed into a few factors wherein information about the underlying data set is retained, but potential collinearity problems are circumvented. For this analysis, the number of factors retained was based on when the running sum of the principal components, after orthogonal rotation, equaled 50% or more of the sum total of the eigenvalues (Johnson and Wichern 2002). Factor membership was determined by inspection of the standardized factor loadings, using 50% as a cut-off.

The factor analysis was performed on two sets of attitudinal questions. One set asked respondents to rate the importance of ten different items on their hypothetical decision to participate in the afforestation program with a Likert scale; one represented “not at all important” and five represented “extremely important” (Table 1). Two factors resulted from the analysis, labeled here as “economics” (*ECONOMICS*) and “social benefits” (*SOCBENES*). Five variables loaded onto the *ECONOMICS* factor: the amount of time/labor required to convert land and manage forestland; investment cost of converting land to forest; amount of paperwork required to participate in the program; limitations on end uses of timber harvested; and per acre program payment offered for converting land to forest. Three variables loaded onto the *SOCBENES* factor: the effect on farm's ability to offset carbon emissions; self-perceived level of knowledge about afforestation practices; and the impact of afforestation on the environment. Thus, respondents with higher scores for the *ECONOMICS* factor were more likely to consider economic factors to be important to their participation decision while those with higher *SOCBENES* scores were more likely to consider the social

benefits of afforestation to be important.

A second set of questions asked respondents about the likelihood that afforesting pasture would change facets of their operation on a five-point Likert scale ranging from “highly unlikely” to “highly likely.” Two factors resulted, one we labeled “environmental benefits” (*ENVIRONMENTAL*) and the other “production benefits” (*PRODUCTION*) (Table 1). Four variables loaded onto the *ENVIRONMENTAL* factor: reduce the amount of soil erosion on your farm; improve water quality in the streams on or near your farm; improve the appearance of your farm; and improve wildlife habitat on your farm. Two variables loaded onto the *PRODUCTION* factor: free up land for other agricultural uses and improve the quality and amount of forage produced on your farm. Thus, respondents with higher *ENVIRONMENTAL* factor scores were more likely to believe afforestation would have implications for the environment on and around their farms, while those with higher *PRODUCTION* scores were more likely to believe afforestation would cause changes in on-farm forage production and land use. In addition, respondent perceptions of the likelihood that afforestation would “increase the profitability of your farming operation” were included as a separate variable in the *AFFOREST* model (*PROFITABLE*, 1 = “yes”) as a measure of the respondent's expectations of the effect of afforestation on farm profits.

3.2. Explanatory variables

Descriptions and summary statistics of the variables included in the regression are provided in Table 2. Explanatory variables for the first hurdle – interest in and willingness to afforest (*AFFOREST*) – include regional characteristics (measured at the county level), farm and farmer characteristics, and opinion variables.

Explanatory variables for the second hurdle – willingness to participate in the afforestation program given the incentive and cost share offered (*COMMIT*) – include the annual per acre incentive payment for participating in the program (*INCENTIVE*) and variables with financial

Table 2
Variable descriptions and descriptive statistics.

Name	Variable description	Mean	N	Minimum	Maximum
Dependent variables					
<i>AFFOREST</i>	1 if willing to afforest, 0 otherwise	0.33	1026	0	1
<i>COMMIT</i>	1 if would participate in program (afforest) given amount of incentive, 0 otherwise	0.53	336	0	1
<i>ACRES</i>	Acres would enroll in program (afforest) given incentive	32.10	170	0	7.83
Independent variables					
<i>INCENTIVE</i>	Annual per acre incentive payment offered (\$60, \$90, \$120, \$150, \$180)	122.85	336	60	180
<i>ACFARM</i>	Total acres farmed	268.75	1026	0.69	9.95
<i>INCOME</i>	Total annual household income ^a	3.97	1026	1	8
<i>RENT</i>	2012–2014 county average annual pasture cash rent (\$/acre)	23.07	1026	3.47	78.00
<i>POPDENSITY</i>	Change in county population density from 2000 to 2010 (%)	5.59	1026	–21.05	46.33
<i>STOCKDENSITY</i>	Cattle stocking rate (animal units/acres) ^b	0.59	1026	0	27.83
<i>OFFFARM</i>	1 if respondent works off farm, 0 otherwise	0.52	1026	0	1
<i>OWNWOOD</i>	1 if respondent owns forested acres, 0 otherwise	0.60	1026	0	1
<i>FORESTED</i>	1 if respondent has previously afforested, 0 otherwise	0.08	1026	0	1
<i>FORSHARE</i>	Share of county land area in forest in 2012 (%)	9.00	1026	0	25
<i>AGE</i>	Age	61.87	1026	18	95
<i>AGESQ</i>	Age squared	3966.59	1026	324	9025
<i>SOMECOL</i>	1 if respondent attended college, 0 otherwise	0.25	1026	0	1
<i>COLLEGE</i>	1 if respondent graduated college, 0 otherwise	0.38	1026	0	1
<i>ECONOMIC</i>	Factor analysis score	0.00	1026	–2.12	1.72
<i>SOCBENES</i>	Factor analysis score	0.00	1026	–2.29	2.04
<i>ENVIRONMENT</i>	Factor analysis score	0.00	1026	–1.61	2.20
<i>PRODUCTION</i>	Factor analysis score	0.00	1026	–1.59	2.47
<i>PROFITABLE</i>	1 if believe participating in afforestation program would increase profits, 0 otherwise	0.15	1026	0	1
<i>LATEADOPT</i>	1 if respondent is late adopter of new technologies, 0 otherwise	0.37	1026	0	1
<i>FAMILY</i>	1 if respondent's family will take over farm, 0 otherwise	0.66	1026	0	1

^a Likert scale: 1 = less than \$10,000, 2 = \$10,000 - \$29,000, 3 = \$30,000 - \$49,000, 4 = \$50,000 - \$99,000, 5 = \$100,000 - \$149,999, 6 = \$150,000 - \$199,999, 7 = \$200,000 - \$499,999, 8 = \$500,000 or more.

^b Stocking density = (0.92*cows + 0.08*calves + 1.35*bulls + 0.6*backgrounder calves + 0.6*stocker calves + 0.92*dairy cows + 0.8*replacement heifers + 0.8*miscellaneous cattle)/total number of pasture acres farmed (Holt, 2013).

Table 3
Hypothesized effects of variables for each hurdle.

Name	Variable description	Hypothesized effects		
		AFFOREST	COMMIT	ACRES
INCENTIVE	Annual per acre incentive payment offered (\$60, \$90, \$120, \$150, \$180)		+	+
ACFARM	Natural log of total acres farmed	+	+	+
INCOME	Total household income (\$)	+	+	
RENT	2012–2014 county average annual pasture cash rent (\$/acre)	–	–	
POPDENSITY	Change in county population density from 2000 to 2010 (%)	–	–	
STOCKDENSITY	Cattle stocking rate (animal units/pasture acres)	–	–	
OFFFARM	1 if respondent works off farm, 0 otherwise	+		
OWNWOOD	1 if owns forested acres, 0 otherwise	+		
FORESTED	1 if has previously afforested, 0 otherwise	+		
FORSHARE	Share of county land area in forest in 2012	+		
AGE	Age	–		
AGESQ	Age squared	+		
SOMECOL	1 if respondent attended college, 0 otherwise	+		
COLLEGE	1 if respondent graduated from college, 0 otherwise	+		
ECONOMIC	Factor analysis score	+		
SOCBENES	Factor analysis score	+		
ENVIRONMENT	Factor analysis score	+		
PRODUCTION	Factor analysis score	+		
PROFITABLE	1 if believe participating in afforestation program would increase profits, 0 otherwise	+		
LATEADOPT	1 if respondent is late adopter of new technologies, 0 otherwise	–		
FAMILY	1 if respondent's family will take over farm, 0 otherwise	+		

implications for participation in the program. Thus, the first hurdle identifies respondents who are “in the market”, i.e., willing to consider afforesting pasture acres, while the second hurdle estimates the amount of compensation needed to induce participation among those who are interested.

The participation intensity model estimates the number of acres that program participants are willing to enroll (ACRES) as a function of *INCENTIVE* and operation scale effects in terms of the total number of acres the respondent farms (ACFARM).

Hypothesized effects of the explanatory variables are summarized in Table 3. The hypothetical *INCENTIVE*, which represents the return to afforesting pasture, is expected to positively influence program participation (*COMMIT*) and participation intensity (*ACRES*) (Kim and Langpap, 2016; Shaikh et al., 2007). Afforestation studies consistently find a positive correlation with farm size (Crabtree et al., 1998, 2001; Duesberg et al., 2014b; Gasson and Hill, 1990), perhaps because larger operations are less constrained by land holdings and can leverage a broader and deeper set of resources. Thus, farm size (ACFARM) is expected to be positively correlated with *AFFOREST*, *COMMIT* and *ACRES*.

Household income (*INCOME*) is expected to be positively correlated with *AFFOREST* and *COMMIT* because higher income may signify access to resources that facilitate operational change. Opportunity cost, represented by the average annual cash rental rate from 2012 to 2014 for pasture in the county in which the respondent farms (*RENT*), and trends in land opportunity costs, represented by the change in county population density from 2000 to 2010 (*POPDENSITY*), are expected to negatively influence *AFFOREST* and *COMMIT*. Increasing population density may be associated with increased development pressure and decreased expectation that forest will be the most profitable land use over the life of the program. The producer's cattle stocking rate (*STOCKDENSITY*) is also expected to negatively influence *AFFOREST* and *COMMIT*, as it implies a constraint on the ability to afforest without reducing herd size.

Having previously afforested farmland (*FORESTED*), owning forested acres (*OWNWOOD*), and living in a county with a higher share of land in forest (*FORSHARE*) are all expected to be positively correlated with *AFFOREST* and *COMMIT* (Crabtree et al., 1998, 2001; Duesberg et al., 2014b; Gasson and Hill, 1990; Gasson and Potter, 1988; Kim and Langpap, 2016; Shaikh et al., 2007). These variables could represent the availability of land suitable for afforestation (Collier et al.,

2002; Duesberg et al., 2013; Frawley and Leavy, 2001; Howley, 2013; McDonagh et al., 2010; Ní Dhubháin and Gardiner, 1994; Ní Dhubháin and Greene, 2009; Selby and Petäjistö, 1995; Watkins et al., 1996), a preference for forested land or economies of scale in forest management and harvest (Shaikh et al., 2007), or more extensive forest experience and knowledge (Crabtree et al., 2001; Collier et al., 2002).

Findings on the effect of producer age on willingness to afforest are mixed (Gasson and Hill, 1990; Schirmer and Bull, 2014; Shaikh et al., 2007; Duesberg et al., 2014a). Prokopy et al. (2008) find that age is often negatively correlated with best management practice adoption. Given the relatively long time horizon associated with the hypothetical program, respondent age (*AGE*) is expected to be inversely related with *AFFOREST*. The square of age (*AGESQ*) is also included to permit a nonlinear relationship between age and willingness to afforest. Off-farm employment (*OFFFARM*) is expected to be positively correlated with *AFFOREST* and *COMMIT* (Duesberg et al., 2014b; Præstholm et al., 2006) because off-farm employment increases demand for labor resources and forestry management may be less labor-intensive than typical agricultural activities (Howley, 2013). Educational attainment (*SOMECOL* and *COLLEGE*) is expected to be positively correlated with *AFFOREST* (Schirmer and Bull, 2011).

The social benefits, environmental benefits, and production benefits factor scores (*SOCBENES*, *ENVIRONMENT*, and *PRODUCTION*, respectively) are expected to have a positive influence on willingness to afforest (Ní Dhubháin and Greene, 2009; Schirmer and Bull, 2011). *SOCBENES* captures the importance of environmental benefits to the respondent's afforestation decision, while *ENVIRONMENT* and *PRODUCTION* reflect respondent perceptions about environmental and production-related benefits associated with afforestation. The *ECONOMIC* factor score controls for cost and revenue factors on the decision to afforest. Respondent belief that afforestation is likely to increase profitability (*PROFITABLE*) is expected to be positively correlated with *AFFOREST* (Crabtree et al., 2001; Howley, 2013; Ní Dhubháin and Gardiner, 1994; Ní Dhubháin and Greene, 2009; Ní Dhubháin and Kavanagh, 2003; Watkins et al., 1996).

Respondents who adopt new technologies or practices only after others have adopted (*LATEADOPTER*) are expected to be less likely to afforest since afforestation is a relatively uncommon practice among cow-calf producers. Given the relatively long time horizon associated with tree growth, respondents who expect that their family will take over the farm (*FAMILY*) may be more likely to afforest. However, the

Table 4

Incentive levels, acceptance rates, mean acreage enrollments and mean acres enrolled as share of mean total acres farmed.

Incentive level	Acceptances		Acceptance rate		Mean acres enrolled		Mean share of total acres farmed (%)	
	Survey	Expanded ^a	Survey	Expanded ^b	Survey	Expanded ^b	Survey	Expanded ^b
\$60	24	2495	41%	39%	184	197	34	32
\$90	26	2634	54%	38%	68	65	19	19
\$120	43	4737	58%	57%	58	57	20	19
\$150	41	4187	58%	55%	61	61	25	26
\$180	42	4768	60%	60%	62	64	25	27
Total	176	18821	53%	51%	79	80	24	25

^a Sum of post-stratification weights for group.^b Weighted calculation.

empirical evidence supporting this hypothesis is mixed (Duesberg et al., 2014b; Gasson and Hill, 1990; Schirmer and Bull, 2011). As Shaikh et al. (2007) note, producers may be unwilling to constrain future generations' land use choices.

4. Results

About 33% of the respondents (336 out of 1026) expressed a willingness to afforest pasture acres. Of these respondents, 176 (53%) were willing to participate in the hypothetical afforestation program at the offered incentive level (Table 4). Respondents willing to participate in the afforestation program were willing to enroll an average of 79 acres (32 ha).

Estimated coefficients, marginal effects and test statistics for the triple hurdle model are provided in Table 5. The pseudo- R^2 value (1 – unrestricted log likelihood/restricted log likelihood) is 0.15. The null hypothesis that the covariates were unrelated to the outcome variables was rejected at the 1% level of significance (Wald statistic = 206, degrees of freedom (df) = 35). The estimates of the error correlation terms (ρ_{12} , ρ_{23} , ρ_{13}) are jointly significant (likelihood ratio statistic = 31,060, df = 3), suggesting that unobserved factors not included in the model are correlated across the decisions. Rejection of the null hypothesis, $H_0: \rho_{12} = \rho_{13} = \rho_{23} = 0$, indicates the triple-hurdle specification is preferred to estimating each equation separately.

Table 5

Estimated coefficients and marginal effects.

	Estimates			Marginal effects		
	ACRES	COMMIT	AFFOREST	ACRES ^a	COMMIT ^b	AFFOREST
INCENTIVE	−0.0041	0.0034***		−0.0118	0.0017	–
ACFARM	0.4594***	0.0203	−0.0051	0.0960	0.0087	−0.0017
INCOME		−0.0529*	0.0044	−3.3127	−0.0032	0.0015
RENT		−0.0077**	0.0023	−0.4845	−0.0020	0.0008
POPDENSITY		−0.0105**	0.0109**	−0.6554	9.48E-03	0.0037
STKDENSITY		0.0132	0.0097	0.8294	−0.0252	0.0033
OFFFARM			0.1280	0.0220	0.0376	0.0436
OWNWOOD			0.2708***	0.1607	0.0796	0.0922
FORESTED			0.5834***	−0.9329	0.1715	0.1987
FORSHARE			−0.0064	−0.0007	−0.0186	−0.0022
AGE			−0.0631**	−0.0135	0.0001	−0.0215
AGESQ			0.0005**			
SOMECOL			0.1799*	−0.0564	0.1003	0.0613
COLLEGE			0.3411***	0.1297	0.0716	0.1162
ECONOMIC			0.2435***	0.0258	0.0983	0.0829
SOCBENES			0.3343***	0.0348	0.0653	0.1139
ENVIRONMENT			0.2221***	0.0234	0.0205	0.0756
PRODUCTION			0.0697	0.0076	0.0992	0.0237
PROFITABLE			0.3376***	−0.2165	−0.0747	0.1150
LATEADOPT			−0.2541***	−0.1181	0.0290	−0.0865
FAMILY			0.0988	−0.9329	−0.0019	0.0337
Constant	1.4405*	0.7494*	0.8576			
N	176	336	1026			
Expanded	19,434	37,184	112,445			
Percent correctly classified		52.54%	77.78%			
Wald test against intercept only (35 df)			206***			
Log likelihood (model)			−110,493			
Log likelihood (null)			−129,402			
σ_1	1.6175***					
ρ_{12}	−0.7708***					
ρ_{13}	0.5358***					
ρ_{23}	−0.9202***					

^a Marginal effect is evaluated using Eq. (11).^b Conditional on $\Pr(\text{AFFOREST} = 1)$.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

4.1. Willingness to afforest

Twenty variables are included in the *AFFOREST* regression, 11 of which are significant at the 10% level or lower (Table 5). The percentage change in county population density from 2000 to 2010 (*POPDENSITY*) is positively correlated with *AFFOREST*, confounding expectations. A 10% increase in population density increases the likelihood of being willing to afforest by 0.037. Perhaps respondents in these counties perceive forests to be more compatible with rapid population growth than livestock production. Respondents who own forested land (*OWNWOOD*) are 0.09 more likely to be willing to afforest, and those who have previously converted land to forest (*FORESTED*) are 0.20 more likely to be willing to afforest. The *FORESTED* variable reflects previous experience with afforestation, while *OWNWOOD* only reflects ownership of forested lands. Both variables control for land suitability for forests, respondent preferences for woodland, and scale economies associated with forest ownership or experience.

Respondent age (*AGE*) is negatively correlated with willingness to afforest. The coefficient for the square of age (*AGESQ*) is positive, indicating a convex relationship between age and willingness to participate. Thus, the results suggest that willingness to participate is higher among younger producers but decreases up to age 64 and then increases as producers approach retirement. Respondents who graduated from college (*COLLEGE*) are 0.12 more likely to be willing to afforest than those who did not attend college.

The coefficients for three of the four factor variables included in the willingness to afforest model are positive and significant. A higher *ECONOMIC* factor score is associated with greater concern about the on-site economics associated with afforestation; namely the amount of time required, investment cost, amount of paperwork, per acre payment offered, and limitations on end uses of timber. Respondents with high scores for the *SOCBENES* factor are more likely to consider the extent to which afforestation offsets carbon emissions and the impact of afforestation on the environment, along with their self-perceived level of knowledge about afforestation, in deciding to participate in the afforestation program. Finally, respondents with higher *ENVIRONMENT* factor scores are more likely to believe that afforestation would improve their operation's appearance, reduce soil erosion, improve water quality, and enhance wildlife habitat on their farm.

Respondents who more strongly believe that participation in the afforestation program could improve the profitability of their farm (*PROFITABLE*) are 0.12 more likely to be willing to afforest. Also conforming to a priori expectations, respondents who tend to wait until others adopt new technologies or practices before they adopt them (*LATEADOPT*) are 0.09 less likely to afforest pasture.

4.2. Willingness to commit to the hypothetical afforestation program

Approximately 52% of the respondents expressing willingness to afforest (and, thus, moving from the first to the second hurdle), indicated they would be willing to participate in the hypothetical afforestation program (*COMMIT*) given the cost share and annual incentive offered. The program participation model includes six explanatory variables, three of which are significant at the 10% level or lower. The coefficient for the amount of the annual per-acre payment offered for participation in the program (*INCENTIVE*) is positive and significant at the 1% level. Increasing the ten-year annual payment for participating in the program by \$10 per acre increases the likelihood of respondent willingness to participate by 0.017. Respondents reporting higher household incomes (*INCOME*), on the other hand, are less likely to participate in the program. As anticipated, willingness to participate is inversely related with the average cash rental rate for pasture (*RENT*). An increase of \$10 in the county average cash rental rate decreases the likelihood a respondent participates by 0.032.

4.3. Participation intensity

The 176 respondents indicating a willingness to afforest and participate in the hypothetical afforestation program, given the annual incentive, were asked how many acres they would convert to forest. The amount of the incentive offered (*INCENTIVE*) does not have a significant influence on acres enrolled ($P > .10$). In other words, the probability of enrolling land is affected by the payment offer, but the acres enrolled are not. This finding is sensible assuming landowners make decisions about their property in terms of parcels. In this case, landowners base decisions on the marginal parcel. The incentive offered therefore affects whether they are willing to enroll that parcel or not. However, the acres offered depends on the size of the marginal parcel and not the payment offer. Thus, while participation in the program is significantly influenced by the per-acre annual payment offered, the number of acres a program participant is willing to enroll in the program is not. On the contrary, while the total acres farmed (*ACFARM*) influences neither willingness to afforest nor willingness to participate in the program, it does influence the number of acres a respondent who is willing to afforest and participate in the program is willing to enroll in the program. Marginal parcels likely tend to be larger on large farms. Given a ten acre increase in the acres farmed, the area enrolled into the program increases by 0.96 acres. Unsurprisingly, the larger the size of the farm (*ACFARM*), the greater the number of acres the participant is willing to enroll.

The conditional mean number of pasture acres enrolled in the hypothetical program is 55 (22.3 ha), compared to the unconditional mean of 21 (8.5 ha). The conditional mean reflects acreage conversion among the 176 respondents who expressed interest in afforestation and commitment to the hypothetical program.

Population density had a negative effect on acres enrolled. A 1% increase in the change in population density was associated with 0.66 fewer acres enrolled. Respondents who owned woodlands enrolled 0.16 more acres than non-owners. Respondents who had previously afforested pasture land enrolled 0.95 fewer acres. Relatively more acres were enrolled by individuals with a college degree (0.13 acres). The factor scores *ECONOMIC* and *SOCBENES* were positively associated with participation intensity, as were factor scores associated with environmental sentiments and benefits of afforestation to their operation's production. Respondents exhibiting aversion to early adoption of practices or technologies enrolled 0.12 fewer acres. Other factors equal, respondents who believed that afforestation would positively affect their profits enrolled relatively fewer acres. The direction of this effect counters our null hypothesis. Expectations about profitability increased the likelihood that respondents expressed interest in afforestation. However, the magnitude and direction of the correlation between the first hurdle and the acreage supply equation translated into an overall negative effect of profitability expectations on participation intensity.

5. Discussion and conclusions

Efforts to promote afforestation of grazing lands are furthered by a clear understanding of cattle producer interest in and willingness to afforest grazing lands. As suggested by previous research, interest in afforestation among US cattle producers east of the 100th meridian is low. Most (71%) respondents were unwilling to afforest their pastureland even "if it was profitable to do so". While respondents' definition of "profitability" may be ambiguous, this finding suggests increasing cattle producer interest in afforestation is likely a precursor to the successful implementation of an afforestation program. Comparing responses to this question with those to a similar question by landowners in the Pacific Northwest (Kim and Langpap, 2016) suggests that livestock producers in the Eastern US are less willing to consider afforestation than agricultural landowners in the Pacific Northwest.

Not surprisingly, producer beliefs about the on- and off-farm effects of the afforestation of grazing lands and their rating of the importance

of various factors to the decision to afforest have a strong effect on willingness to afforest. These results are useful for constructing outreach to producers interested in afforestation or to address producer questions or concerns about the practice. Other correlations between farm and farmer characteristics and willingness to afforest suggest possibilities for cost-effectively targeting producers. For example, as evidenced by the marginal effects, higher education institutions that track alumni from farming backgrounds or who still farm could coordinate informational campaigns with entities that could financially support recruitment into an afforestation program. Individuals with a college degree were 0.12 more likely to express interest in an afforestation program, and also 0.07 more likely to commit to an incentive. This subgroup would, on average, enroll 0.13 more acres than their peers who did not graduate with a college degree. Thus, these results suggest that efforts to promote afforestation among younger, more educated producers who have forested acres or live in an area with extensive forest and relatively low population growth may be more effective. Conversely, a number of factors did not influence producer willingness to afforest, including farm size, household income, stocking density, off-farm employment, respondent' expectations that his/her family will take over the farming operation, the factor analysis score associated with potential production-oriented impacts of afforestation, and two county-level variables – average pasture rental rate and share of land area in forest. The failure of either the stocking density or production factor analysis score to have a significant effect suggests that unwillingness to consider afforestation may not be tied to production constraints. Thus, future studies of willingness to afforest might benefit from incorporating a broader range of socio-economic and psychological variables (Willock et al., 1999).

Over half (56%) of the respondents who were generally willing to afforest or, given the structure of the model, about 16% of all respondents, were willing to participate in a hypothetical afforestation program. Willingness to participate was positively correlated with the amount of the incentive offered but negatively correlated with household income and the average cash pasture rental rate for the county where the respondent resides. The negative effects of household income and average pasture rental rate on willingness to participate could reflect higher opportunity costs to program participation.

Respondents who were willing to participate in the afforestation program were willing to afforest a modeled average of 55 acres (22 ha), given the incentive offered. While the amount of the incentive positively influenced willingness to participate, it did not significantly influence the number of acres those who were willing to participate were willing to enroll. This finding, which echoes similar results on land enrollment (e.g. Ma et al., 2012; Skevas et al., 2016; Swinton et al., 2017), has important implications for designing programs and incentive systems to promote afforestation. For one, these results suggest that marginal increases in the amount of the incentive offered might increase participation rates and administrative costs, but are unlikely to have much of an effect on the number of acres that individual participants are willing to enroll. They could also suggest that targeting larger

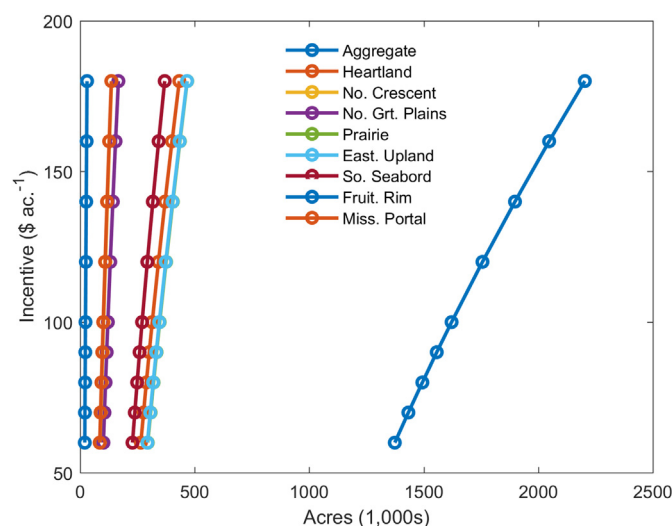


Fig. 5. Regional and aggregate acreage supply curves.

operations would be an effective strategy for maximizing acres enrolled.

Respondents who expressed an unwillingness to afforest were considered averse to supply any acreage at any incentive level. The results extrapolated to the population of beef cattle operations with at least 20 head of cattle in the eight ERS regions using the expansion factors. Regional and aggregate supply curves were estimated using Eq. (11). The coefficient on the incentive level of Eq. (9) was set to zero, and the function evaluated for each individual after changing the incentive level in increments of \$10 (range, the minimum and maximum levels appearing in the survey; \$60 and \$180, respectively). The farm-level acres were subsequently aggregated for each region, and for the entire study region (Table 6). The resulting regional and aggregate acreage supply functions are graphed in Fig. 5. The aggregate amount of acreage enrolled into the hypothetical program ranges from 1.4 million acres (555,742 ha) for an annual incentive of \$60 per acre per year to 2.2 million acres (891,472 ha) for an incentive of \$180. These totals represent 0.2% to 0.4% percent of all US pasture land, respectively (Nickerson et al., 2011).

The amount of carbon sequestration associated with this level of afforestation can be approximated using the range of carbon sequestration rates for afforestation of pasture land reported by Kim and Langpap (2016) of 2.7 to 7.7 metric tons of carbon dioxide (CO₂) equivalent ha⁻¹ yr⁻¹. Given these estimates, the total amount of carbon sequestered for an annual incentive of \$60 per acre could range from 1.5 million metric tons to 4.3 million metric tons, or from 0.6 to 1.75% of the approximately 245 million metric tons of CO₂ equivalent US livestock operations are estimated to have produced from enteric fermentation and manure management in 2014 (USEPA, 2016). For an annual incentive payment of \$180 per acre, the total amount of carbon

Table 6
Expanded enrollment estimates and carbon sequestered.

ERS region	Estimated hectares enrolled (1000s)	Standard error	Metric tons carbon year ⁻¹ (1000s)	Standard error
Heartland	72	5.7	194 to 552	15.4 to 43.9
Northern Crescent	25	6.7	67 to 192	18.0 to 51.4
Northern Great Plains	37	5.6	100 to 284	15.0 to 42.8
Prairie Gateway	84	14.5	226 to 644	39.1 to 111.6
Eastern Upland	111	10.4	300 to 856	28.1 to 80.2
Southern Seaboard	72	8.7	195 to 556	23.4 to 66.7
Fruitful Rim	4	0.7	12 to 34	2.0 to 5.7
Mississippi Portal	27	3.0	72 to 205	8.2 to 23.3
Total	432		1165 to 3323	

Notes: Area enumerated directly from survey.

sequestered could range from 2.4 million metric tons to 6.9 million metric tons, or from 1 to 2.8% of the CO₂ equivalent produced by US livestock operations. At these levels of acreage supply and carbon sequestration, program costs for an annual incentive payment of \$60 per acre would be \$82 million, or from \$19 to \$55 per metric ton of CO₂ equivalent. Programs costs for an annual incentive payment of \$180 per acre would be \$397 million, or from \$58 to \$165 per metric ton of CO₂ equivalent.

A related topic that was not a focus of this research is agroforestry or joint cattle and woodland operation. Agroforestry can provide many benefits to a cattle operation such as shade, wind protection, and erosion reduction. Further research might try to capture these motivations to better understand cattle producer views of afforestation. Knowing these motivations could help policy makers design and implement effective programs to increase conservation efforts while maintaining farm and forest productivity.

Finally, thorough analysis of the potential effects of a program to incentivize afforestation to promote carbon sequestration would require careful consideration of the possible unintended consequences of such a program. The resulting change in land use could have important implications along other environmental, economic and social dimensions. However, the nature of these effects may depend on the secondary land use changes, i.e., what happens on the land that is not afforested. Thus, while afforestation may reduce nutrient runoff and improve habitat for native species, increased stocking density on other lands could actually lead to increased runoff and degraded habitat. Conversely, if program payments primarily benefit absentee landowners and/or the aggregate size of the cattle herd decreases, the program could have adverse effects on rural economies. While decreasing herd sizes could, in the short run, lead to reductions in GHG emissions, it could also boost meat and dairy prices over the longer term, making it less likely that afforested land would remain so after program expiration.

Acknowledgements

This project was supported by Agriculture and Food Research Initiative Competitive Grant No. 10642663 from the United States Department of Agriculture, National Institute of Food and Agriculture.

The authors would also like to acknowledge the helpful comments of three anonymous reviewers. The views are those of the authors.

References

- Cameron, A.C., Trivedi, P.K., 2009. *Microeconometrics Using STATA*. STATA Press, College Station, TX.
- Collier, P., Dorgan, J., Bell, P., 2002. Factors Influencing Farmer Participation in Forestry. COFORD, Dublin.
- Cottle, D.J., Nolan, J.V., Wiedemann, S.G., 2011. Ruminant enteric methane mitigation: a review. *Anim. Prod. Sci.* 51, 491–514.
- Crabtree, B., Chalmers, N., Barron, N.-J., 1998. Information for policy design: modelling participation in a farm woodland incentive scheme. *J. Agric. Econ.* 49 (3), 306–320.
- Crabtree, B., Chalmers, N., Eiser, D., 2001. Voluntary incentive schemes for farm forestry: uptake, policy effectiveness and employment impacts. *Forestry* 74 (5), 455–465.
- Clark, G.M., Johnson, J.A., 1993. Farm woodlands in the central belt of Scotland: a socio-economic critique. *Scott. For.* 47, 15–24.
- Duesberg, S., O'Connor, D., Dhubháin, Á.N., 2013. To plant or not to plant—Irish farmers' goals and values with regard to afforestation. *Land Use Policy* 32, 155–164.
- Duesberg, S., Dhubháin, Á.N., O'Connor, D., 2014a. Assessing policy tools for encouraging farm afforestation in Ireland. *Land Use Policy* 38, 194–203.
- Duesberg, S., Upton, V., O'Connor, D., Dhubháin, Á.N., 2014b. Factors influencing Irish Farmers' afforestation intention. *For. Policy Econ.* 39, 13–20.
- Feng, H., Kurkalova, L.A., Kling, C.L., Gassman, P.W., 2006. Environmental conservation in agriculture: land retirement vs. changing practices on working land. *J. Environ. Econ. Manag.* 52 (2), 600–614.
- Follett, R., Kimble, J., Lal, R., 2001. *The Potential of US Grazing Lands to Sequester Soil Carbon*. Lewis Publishers, Boca Raton, Florida.
- Frawley, J.P., 1998. Farmers' attitudes towards forestry as a farm enterprise in Ireland. In: Wiersum, F.K. (Ed.), *Forestry in the Context of Rural Development, Proceedings of The Final Scientific Conference COST Action E3*. Vila Real, Portugal.
- Frawley, J., Leavy, A., 2001. *Farm Forestry: Land Availability, Take-up Rates and Economics*. Rural Economy Research Series The Rural Economy Research Centre, Teagas.
- Gasson, R., Hill, P., 1990. An Economic Evaluation of the Farm Woodland Scheme. Occasional Paper No.17. Farm Business Unit, Wye College, Kent.
- Gasson, R., Potter, C., 1988. Conservation through land diversion: a survey of Farmer's attitudes. *J. Agric. Econ.* 39 (3), 340–351.
- Gerber, P.J., Hristov, A.N., Henderson, B., Makkar, H., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A.T., Yang, W.Z., Tricarico, J.M., Kebreab, E., Waghorn, G., Dijkstra, J., Oosting, S., 2013. Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review. *Animal* 7 (s2), 220–234.
- Gillespie, J., Kim, S., Paudel, K., 2007. Why don't producers adopt best management practices? An analysis of the beef cattle industry. *Agric. Econ.* 36 (1), 89–102.
- Gould, W.W., Pitblado, J.S., Poi, B.P., 2010. *Maximum Likelihood Estimation with Stata*, 4th ed. Stata Press, College Station, TX.
- Holt, C.E., 2013. Producers Willingness to Adopt a Prescribed Grazing System East of the 100th Meridian. Master's Thesis. University of Tennessee. http://trace.tennessee.edu/utk_gradthes/2610.
- Howley, P., 2013. Examining farm Forest Owners' Forest Management in Ireland: the role of economic, lifestyle and multifunctional ownership objectives. *J. Environ. Manag.* 123, 105–112.
- Hristov, A.N., Ott, T., Tricarico, J., Rotz, A., Waghorn, G., Adesogan, A., Dijkstra, J., Montes, F., Oh, J., Kebreab, E., Oosting, S.J., Gerber, P.J., Henderson, B., Makkar, H.P.S., Firkins, J.L., 2013a. Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *J. Anim. Sci.* 91, 5095–5113.
- Hristov, A.N., Oh, J., Firkins, J.L., Dijkstra, J., Kebreab, E., Waghorn, G., Makkar, H.P.S., Adesogan, A.T., Yang, W., Lee, C., Gerber, P.J., Henderson, B., Tricarico, J.M., 2013b. Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *J. Anim. Sci.* 91, 5045–5069.
- Jensen, K.L., Lambert, D.M., Clark, C.D., English, B.C., Yu, T.E., Larson, J.A., Holt, C., Hellwinckel, C.M., 2015. Cattle producers' willingness to adopt or expand prescribed grazing in the United States. *J. Agric. Appl. Econ.* 47 (2), 213–242. <http://dx.doi.org/10.1017/aae.2015.6>.
- Johnson, R.A., Wichern, D.W., 2002. *Applied Multivariate Statistical Analysis*, 5th edition. Prentice Hall, Upper Saddle River, NJ.
- Kassiomis, K., Papageorgiou, K., Christodoulou, A., Blioumis, V., Stamou, N., Karameris, A., 2004. Rural development by afforestation in predominantly agricultural areas: issues and challenges from two areas in Greece. *For. Policy Econ.* 6, 483–496.
- Kim, Taeyoung, Langpap, Christian, 2016. Agricultural landowners' response to incentives for afforestation. *Resour. Energy Econ.* 43, 93–111.
- van Kooten, G.C., Shaikh, S.L., Suchánek, P., 2002. Mitigating climate change by planting trees: the transaction costs trap. *Land Economics* 78 (4), 559–572.
- van Kooten, G.C., Eagle, A.J., Manley, J., Smolak, T., 2004. How costly are carbon offsets? A meta-analysis of carbon forest sinks. *Environmental Science & Policy* 7, 239–251.
- Lambert, D.M., English, B.C., Harper, D.S., Larkin, S.L., Larson, J.A., Mooney, D.F., Roberts, R.K., Velandia, M., Reeves, J.M., 2014. Adoption and frequency of precision soil testing in cotton production. *J. Agric. Resour. Econ.* 39 (1), 115–132.
- Lee, J., Dodson, R., 1996. Potential carbon sequestration by afforestation of pasture in the south-Central United States. *Agron. J.* 88, 381–384.
- Lubowski, R.N., Plantinga, A.J., Stavins, R.N., 2006. Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function. *J. Environ. Econ. Manag.* 51 (2), 135–152.
- Luo, J., de Klein, C.A.M., Ledgard, S.F., Saggar, S., 2010. Management options to reduce nitrous oxide emissions from intensively grazed pastures: a review. *Agric. Ecosyst. Environ.* 136, 282–291.
- Ma, S., Swinton, S.M., Lupi, F., Jolejole-Foreman, C., 2012. Farmers' willingness to participate in payment-for-environmental-services programmes. *J. Agric. Econ.* 63 (3), 604–626.
- Mather, A., 1998. The changing role of forests. In: Ilberry, B. (Ed.), *The Geography of Rural Change*. Routledge, Oxon, pp. 106–128.
- McDonagh, J., Farrell, M., Mahon, M., Ryan, M., 2010. New opportunities and cautionary steps? Farmers, forestry and rural development in Ireland. *Eur. Countryside* 2, 236–251.
- Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A.N., Oh, J., Waghorn, G., Gerber, P.J., Henderson, B., Makkar, H.P.S., Dijkstra, J., 2013. Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *J. Anim. Sci.* 91, 5070–5094.
- Moulton, R.J., Richards, K.R., U.S. Forest Service, 1990. *Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States*. U.S. Dept. of Agriculture, Forest Service.
- Ní Dhubháin, Á., Gardiner, J., 1994. Farmers' attitudes to forestry. *Irish For.* 51 (1&2), 21–26.
- Ní Dhubháin, Á., Greene, R., 2009. How much do Irish private forest owners know about forestry? *Small-Scale For.* 8 (3), 249–262.
- Ní Dhubháin, Á., Kavanagh, T., 2003. Joint ventures in private forestry in Ireland. *Small-Scale For.* 2, 9–19.
- Ní Dhubháin, A., Wall, S., 1999. The new owners of small private forests in Ireland. *Journal of Forestry* 97 (6), 28–33.
- Nickerson, C., Ebel, R., Borchers, A., Carriazo, F., 2011. *Major Uses of Land in the United States, 2007*. EIB-89. U.S. Department of Agriculture, Economic Research Service (December).
- Parks, P.J., Hardie, I.W., 1995. Least-cost forest carbon reserves: cost-effective subsidies to convert marginal agricultural land to forests. *Land Econ.* 71 (1), 122–136.
- Præstholm, S., Reenberg, A., Kristensen, S.P., 2006. Afforestation of European landscapes: How do different farmer types respond to EU agri-environmental schemes? *GeoJournal* 67, 71–84.

- Prokopy, L., Floress, K., Klotthor-Weinkauff, D., Baumgart-Getz, A., 2008. Determinants of agricultural best management practice adoption: evidence from the literature. *J. Soil Water Conserv.* 63 (5), 300–311.
- Qualls, D.J., Jensen, K.L., Clark, C.D., English, B.C., Larson, J.A., Yen, S.T., 2012. Analysis of Factors Affecting Willingness to Produce Switchgrass in the Southeastern United States. *Biomass & Bioenergy* 39, 159–167.
- Richards, K.R., Stokes, C., 2004. A review of Forest carbon sequestration cost studies: a dozen years of research. *Clim. Chang.* 63 (1–2), 1–48.
- Roodman, D., 2011. Estimating fully observed recursive mixed-process models with cmp. *Stata J.* 11 (2), 159–206.
- Selby, A., Petäjäistö, L., 1995. Attitudinal aspects of the resistance to field afforestation in Finland. *Sociol. Rural.* 35, 67–92.
- Schirmer, J., Bull, L., 2011. Planting Trees for Carbon Sequestration: What do Landholders Think? Cooperative Research Centre for Forestry, Hobart.
- Schirmer, J., Bull, L., 2014. Assessing the likelihood of widespread landholder adoption of afforestation and reforestation projects. *Glob. Environ. Chang.* 24, 306–320.
- Shaikh, S.L., Sun, L., Van Kooten, G.C., 2007. Are agricultural values a reliable guide in determining landowners' decisions to create Forest carbon sinks? *Can. J. Agric. Econ.* 55 (1), 97–114.
- Skevas, T., Hayden, N.J., Swinton, S.M., Lupi, F., 2016. Landowner willingness to supply marginal land for bioenergy production. *Land Use Policy* 50, 507–517.
- Swinton, S.M., Tanner, S., Barham, B.L., Mooney, D.F., Skevas, T., 2017. How willing are landowners to supply land to grow bioenergy crops in the northern Great Lakes region? *Glob. Change Biol. Bioenergy* 9 (2), 414–428.
- U.S. Department of Agriculture-Economic Research Service, 2000. Farm Resource Regions. Agricultural Information Bulletin Number. D.C, Washington, pp. 760.
- U.S. Environmental Protection Agency (USEPA), 2016. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014. Washington, DC, Available online at: <http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html>.
- Van de Ven, W.P.M.M., Van Pragg, B.M.S., 1981. The demand for deductibles in private health insurance: a probit model with sample selection. *J. Econ.* 17, 229–252.
- Watkins, C., Williams, D., Lloyd, T., 1996. Constraints on farm woodland planting in England: a study of Nottinghamshire farmers. *Forestry* 69, 167–176.
- Willock, J., Deary, I.J., Edwards-Jones, G., Gibson, G.J., McGregor, M.J., Sutherland, A., Dent, J.B., Morgan, O., Grieve, R., 1999. The role of attitudes and objectives in farmer decision making: business and environmentally oriented behaviour in Scotland. *J. Agric. Econ.* 50 (2), 286–303.
- Yen, S.T., Rosinski, J., 2008. On the marginal effects of variable in the log-transformed sample selection models. *Econ. Lett.* 100, 4–8.